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ALLOY STEELS

THEIR COMPOSITION, CHARACTERISTICS, STRENGTH AND HEAT-TREATMENT

BY E. F. LAKE

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NUMBER 118

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CONTENTS

CHAPTER I

NICKEL STEEL

Nickel steel is used to a large extent in the construction of high-grade machinery, and can be purchased in the open market in almost any percentages of nickel up to 35 per cent, and with the carbon component varying between 0.10 and 1.00 per cent. Nickel was added to carbon steel as the result of investigations which were started for the purpose of overcoming the "sudden rupture" that is inherent in all carbon steel. This property or tendency of carbon steel to rupture is the subject of numerous investigations by the railroads of the country at the present time, owing to the many accidents that have occurred in the past few years due to broken rails. Nickel added to steel largely overcomes this tendency, and nickel steel is used successfully for parts of machinery that have to withstand severe shocks and torsion, such as the crankshafts and connecting-rods of internal combustion engines, propeller shafts, automobile axles, and other parts of a similar nature which have to withstand similar strains and stresses.

If nickel is added to steel in any percentage not exceeding 8 per cent, the tensile strength and the elastic limit of the steel will increase with the percentage of nickel. If the percentage of nickel is above 8 per cent, but less than 15 per cent, its effect on the steel becomes, for some reason, entirely neutralized and brittleness is produced. If the nickel percentage, however, is above 15 per cent, then the strength and elasticity become practically equal to that of the nickel steels with percentages of nickel less than 8 per cent. If the nickel percentage is increased above 20 per cent, the strength and elastic limit gradually decrease, but the elongation increases.

The elongation shows a slight rise until about 3 per cent of nickel is added to the steel, and after that it shows a rapid decrease, until the zone of brittleness is reached, when it becomes nil. With from 20 to 25 per cent nickel, the elongation again rapidly rises, and from that point to 100 per cent it shows a slight increase. The best results, therefore, in steels that are used for machine parts are obtained with a nickel content of 3½ per cent, although for some purposes 5 per cent nickel steel is used at a sacrifice of the elongation.

Beneficial Effects of Nickel in Heat Treatment

The qualities of carbon steel are susceptible of change by heat-treatment the same as are those of alloy steels, but the higher the carbon content is the more likely is the steel to burn and thereby reduce its strength, and it is extremely difficult to caseharden steels which contain more carbon than does mild steel without destroying their good qualities and strengths By the addition of nickel

tendency to burn is largely overcome, and the susceptibility to heat-treatment is remarkable. This is best illustrated by Table I in which a nickel steel was given different degrees of hardness. Its composition was as follows: Nickel, 3 per cent; carbon, 0.30 per cent; manganese, 0.40 per cent; phosphorus, 0.05 per cent; sulphur, 0.04 per cent.

A good quality, open-hearth, 0.30 per cent carbon steel, as received from the mill in the untreated state, shows the same strength as the untreated nickel steel in Table I, but it cannot be raised to much more than one-half of the strength of the nickel steel in its hardest state, and even then it is much more liable to fracture under shock tests.

Nickel increases the ability of steel to withstand shock stresses even though the shape be intricate and lightened with holes. When

TABLE I. STRENGTH OF NICKEL STEEL AT DIFFERENT DEGREES OF HARDNESS

Hardness	Tensile Strength, Pounds per Square Inch	Elastic Limit, Pounds per Square Inch	Elongation in 2 Inches, Per Cent	Reduction of Area, Per Cent
Annealed...........	88,000	60,000	28	58
Medium hard.......	130,000	130.000	20	6
Hard...............	220,000	190,000	12	37
Very hard..........	225,000	225,500	8	19

Machinery

properly combined with carbon, it largely removes the tendency of crystallization, and the steel may be casehardened without fear of the core being brittle. If high in carbon, however, it will not stand local hardening, but may be hardened in oil without difficulty.

What the Microscope Reveals in Testing Steels

Steel subjected to different heat-treatments shows different properties when examined under a microscope, and microscopy is, therefore, becoming one of the methods of examining and testing different steels. If we take a piece of steel containing less than 0.85 per cent of carbon, polish it, attack it with a few drops of picric acid and examine it under a microscope, the results will differ according to its composition and the treatment it has undergone. In a piece of steel that has been cooled slowly, small dark masses will appear which are more numerous the closer the carbon is to 0.85 per cent.

Next, heat this steel to 1400 degrees F., or a dull red, and quench in water, then polish, attack with picric acid, examine under the microscope as before, and it will show extremely fine lines intersecting each other in the direction of the sides of an equilateral triangle. Therefore, it is evident that by annealing or heating and quenching this steel we can change its structure, and its condition *is readily* determined by the aid of a powerful microscope.

Other molecular changes take place in heat-treating steels and some of these are governed by the carbon contents. If certain steels are given the heat-treatments just described, the average blacksmith would try them with a file, and if the file bites as well as it did before heat-treating, he would throw the steel out as not hardened, yet transformations have taken place, and tests would show that the tensile strength and elastic limit have been raised while the elongation and reduction of area are reduced. In the case of the nickel steel of which Table I shows the test, these transformations have caused a variation in strength from 88,000 pounds to 225,000 pounds per square inch; this would have been considered impossible a few years ago.

TABLE II. EFFECT OF HEAT-TREATMENT ON NICKEL STEEL OF THE FOLLOWING COMPOSITION:

Nickel, 2.51 per cent; Silicon, 0.26 per cent; Carbon, 0.33 per cent; Manganese, 0.43 per cent; Phosphorus, 0.023 per cent; Sulphur, 0.032 per cent

Treatment	Tensile Strength, Pounds per Sq. In.	Elastic Limit, Pounds per Sq. In.	Elongation in 2 Inches, Per Cent
Quenched at 1600° F.	225,000	208,000	4
Quenched at 1600° F., tempered at 600°	215,000	201,000	6
Quenched at 1600° F., tempered at 800°	190,000	150,000	9
Quenched at 1600° F., tempered at 1000°	170,000	145,000	12
Quenched at 1600° F., tempered at 1200°	155,000	125,000	14
Quenched at 1600° F., tempered at 1400°	135,000	98,000	17
Quenched at 1600° F., tempered at 1600°	104,000	65,000	24

Machinery

Thus annealing, hardening and tempering steel are resorted to for raising the tensile strength, elastic limit, and its ability to withstand shock and torsional stresses, as well as to put a fine cutting edge on tool steels.

Need for Annealing

In heat-treating steels for strength, and especially nickel steel, it should always be remembered that hardening by quenching produces internal strains which can only be removed or destroyed by tempering or drawing after quenching. Thus nickel steel cannot be used in its hardest state, in which it has the highest tensile strength and elastic limit; but the piece must be tempered, thereby reducing the strength and increasing the elongation in order to reduce the brittleness as well as the internal strains caused by hardening. These internal strains may also be caused by forging, hammering or working, and the best results will be obtained if the steel is annealed after each important operation.

Liability of Nickel Steel to Warp, Decarbonize and Cra

Three things work to the detriment of nickel stee' always be taken into consideration when hardening it.

always warps in quenching; second, it may be decarbonized in heating; and third, fissures and cracks might occur in quenching. There are several rules which can be followed to minimize the tendency of steel to warp in quenching. If a piece is cut from stock that has been subjected to some mechanical treatment, it is very liable to be deformed on being heated, and it is undeniable that of the deformations attributed to the hardening process, a large part are due to the heating which precedes quenching, and results from the use of metal which has been mechanically worked. To overcome this, the steel should be thoroughly annealed before it is machined to size, so that the metal will be in a state of repose.

In quenching, the piece should be immersed in the bath in the direction of its principal axis of symmetry, so that the liquid can cover the greatest possible surface, and it should never be thrown into the bath. Thus a shaft should be immersed vertically and a gear wheel perpendicular to its plane. The piece should also be agitated in the bath so as to destroy the coating of vapor which usually forms around the piece and prevents its cooling rapidly.

To reduce the tendency to decarbonize, it is necessary to provide against oxidation; therefore, the pieces must be prevented from coming in contact with the gases. This can be done by placing the pieces in a protecting retort, or by using a metallic heating bath, such as lead.

Fissures or cracks which occur in hardening are caused by the different parts of the piece cooling unevenly, thus producing internal stresses of enormous proportions. These fissures may be prevented by reducing the rate of cooling in three different ways. One method is to cover water with oil from one inch to one inch and a quarter in depth. The second is to cool the pieces in a bath of a comparatively limited volume, so that the cooling is followed by a slight tempering, and the third is to withdraw the piece from the bath before it is completely cooled. This last requires considerable skill, if uniform results are to be obtained.

Nickel Steel for Gears

Nickel steel, when carbonized, is one of the best steels on the market for gears, as different tests have shown that 2 per cent of nickel added to the ordinary carbonizing steel will double, and in some cases more than double, the tensile strength after carbonizing, and these tests would prove that nickel steel should be used for carbonizing wherever the difference in price will warrant doing so. It is from 2 to 2½ cents per pound higher in price than the ordinary carbonizing steel, but the greater safety in manufacturing, and a consequent decrease in the number of spoiled pieces, will largely balance this difference in price.

The different materials used in carbonizing have different effects as to the penetration of the carbon and the time required for a certain

penetration; but a general rule for the rate of penetration at different degrees of temperature is as follows, the time being eight hours:

DEPTH OF PENETRATION OF CARBONIZING MATERIAL AT DIFFERENT TEMPERATURES

Temperature, Degrees F.	Depth of Penetration, Inch	Temperature, Degrees F.	Depth of Penetration, Inch
1300	0.000	1750	0.110
1475	0.0195	1800	0.125
1565	0.039	1850	0.165
1650	0.0625	1900	0.195
1700	0.080	....	....

Thus it will be seen that a rise in temperature of 150 degrees doubles the rate of penetration, and in one case a rise of 90 degrees has doubled it.

With the temperature held stationary at 1850 degrees the speed of penetration is as follows:

Time, Hours	Depth of Penetration, Inch	Time, Hours	Depth of Penetration, Inch
¼	0.000	4	0.500
½	0.020	6	0.800
1	0.310	8	1.200
2	0.400	..	....

The steel used for carbonizing should not contain over 0.20 per cent of carbon, and the manganese component should be low, as this has a tendency to produce crystallization in annealing, and cause brittleness.

The carbonizing material used should be of a definite composition which does not act abruptly, such as 60 per cent powdered charcoal and 40 per cent carbonate of barium. Two rules might be followed in treating: one is to carbonize at 1600 degrees F., cool to 1400 degrees, and quench; and the other is to carbonize at 1850 degrees, quench at 1650 degrees, reheat, and quench a second time at 1400 degrees F.

Nickel steel is not as high a grade of steel as nickel-chrome steel or the newer vanadium steel, but it stands a good second to these at about two-thirds the price, and is so much more easily machined and forged than nickel-chrome steel that it is often used in preference to the higher grades.

Care Required in Forging and Working

In forging, great care must be taken to keep this steel at a high full forging heat and never hammer or roll it below this temperature, as cracks are then liable to appear. A great deal is said among the users of nickel steel about its cracking badly and being defective, and if defects occur in the bloom, they will almost always show up somewhere in the finished product, but if the steel is properly rolled and forged these defects and cracks will not appear. Where carbon steel has been used for automobile axles and given way from fatigue, crystallization or other causes, h[illegible] l steel has been substituted, and has given perfect

Proportion of Carbon

Frequently it is stated in advertisements and elsewhere that a 2 per cent nickel steel is used for various parts of a machine, but this means nothing by itself, as the properties of the steel depend as much upon the carbon content as on the nickel. To illustrate, one nickel steel that is largely used, and is the best for certain purposes, contains 2 per cent nickel and 0.12 per cent carbon. It has a high

TABLE III. INFLUENCES OF DIFFERENT PERCENTAGES OF NICKEL IN NICKEL STEEL

Per Cent of Nickel	Tensile Strength, Pounds per Sq. In.	Elastic Limit, Pounds per Sq. In.	Elongation in 4.72 Ins., Per Cent	Treatment
1 to 1½	78,000	48,000	18	Water tempered at 1650° F.
2½ to 3½	97,000	82,500	15	Medium hard
2½ to 3½	80,000	68,000	20	Medium soft
2½ to 3½	85,000	60,000	23 to 13	Medium hard, structural
2½ to 3½	71,000	50,000	28 to 16	Medium soft, structural
4½ to 6	102,000	74,000	15	Hard, for strenuous work
4½ to 6	121,000	107,000	12	Hard, but annealed at 1600° F.
4½ to 6	88,000	63,000	20	Medium hard
16 to 18	199,000	114,000	6	Annealed at 1650°
22 to 26	110,000	45,000	40	Annealed at 1650°
22 to 26	114,000	50,000	35	Annealed at 1650°
30	80,000	28,000	44	Annealed at 1650°

Machinery

tensile strength and very little elongation, while another nickel steel, equally good for other purposes, contains 2 per cent nickel and 0.9 per cent carbon, and has a high tensile strength with a great elongation.

Table III shows the different percentages of nickel in steel made by one firm, and the strength due to different treatments. These steels have a carbon content ranging from 0.10 to 1.00 per cent. Those with the highest percentages of nickel are used mostly for valves, owing to their heat-resisting powers, combined with a great strength. Sometimes from 1 to 3 per cent of chromium is added to these valve metals to increase the elastic limit.

CHAPTER II

NICKEL-CHROMIUM STEEL

Of the many higher grades of steel which have been brought out in the past few years, nickel-chromium steel has, by both laboratory and practical tests, been placed in the front rank as the highest grade of steel manufactured, and it is used on all classes of high-grade machinery that require a steel of high tensile strength, high elastic limit, and a great resistance to shock and torsional stresses. It is one of the latest products of the steel maker. Ten or fifteen years ago this alloy of steel was comparatively little known, and it was a boast of the Germans "that the entire steel trust of the United States could not duplicate a Mercedes front axle." In the last few years that boast, however, has ceased to be true. To-day this alloy is being produced by a number of American steel makers at a price much below that which the Krupp works obtained for its highest grade of steel. Nickel-chromium steel is made in many different compositions, some of which are high in tensile strength, some in elastic limit, and others having different qualities, demanded by the different uses to which they are to be put.

The Effect of Chromium

Chromium added to steel in amounts up to 5 per cent increases the tensile strength and resistance to shocks, and diminishes the elongation, while further additions lower the tensile strength. The elastic limit, in pieces not annealed, is raised at first, and afterward lowered. Chromium resembles carbon in its influence on the hardening qualities of steel. It refines the grain remarkably, owing to its tendency to prevent the development of a crystalline structure. Added to nickel steel, it overcomes the tendency of lamination and increases the elastic limit to figures that were impossible before it was brought into use. When nickel-chromium steel is given proper heat-treatment, it practically shows no grain or fiber, thus possessing a high power of resistance to shock. This alloy also strongly resists the propagation of cracks which may be produced by sudden strains. Chromium intensifies the sensitiveness of the steel to the quenching process, and the resistance to fracture is higher than in carbon steel of the same degree of hardness; for this reason extreme hardness may be obtained.. Two per cent or more of chromium added to steel makes it very difficult to cut cold, although a special tool steel is made which overcomes this difficulty to a large degree. The influence of chromium on steel becomes decisive above a content of one per cent.

The effect of chromium on steel is best illustrated by the diagram, Fig. 1, adapted from Austen's "Introduction to Metallurgy." The l— dotted line shows the tensile strength of annealed pieces, t

full line shows the elastic limit of annealed pieces, the upper dotted line shows the tensile strength of the steel when hardened, and the upper full line shows the elastic limit of the steel when hardened.

The reason why chromium steels do not fracture in heat-treatment as easily as carbon steels is due to the fact that in chromium steels the critical changes that take place when heating all steels to the hardening temperature take place more slowly. Chromium is also one of the best elements in a steel that is to be carbonized or casehardened, as it greatly increases the susceptibility of steel to heat-treatment and acts as a carrier of the carbon. Thus, in steels containing chromium, the carbon will penetrate to a much greater depth, and a higher percentage will be absorbed by the outer layer in a given time, than with any other kind of steel, especially carbon steel. The increase in

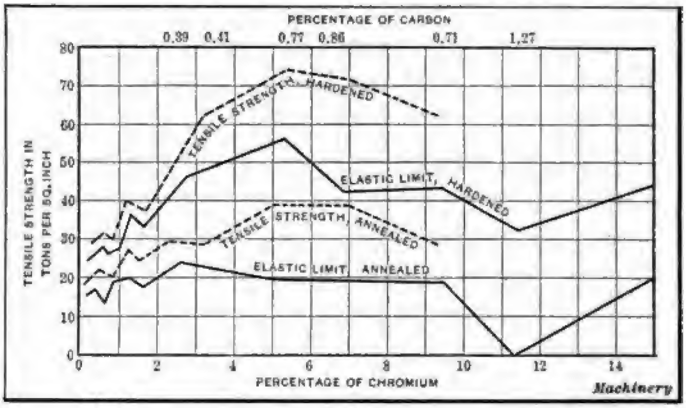

Fig. 1. Diagram Showing Effect of Chromium on Steel

depth of penetration of carbon is about 30 per cent of the penetration in ordinary carbon steels.

The chromium refines the grain of the steel remarkably, owing to its tendency to prevent the development of a crystalline structure. In the annealed state, every increase of chromium up to a content of 6.50 per cent raises the tensile strength, while the elastic limit is gradually raised until a chromium content of 3.00 per cent is reached. This latter remains constant until the chromium content has passed 9 per cent, but after this a rapid reduction takes place. In the hardened steels, both the tensile strength and the elastic limit increase until a chromium percentage of 5.00 per cent has been reached, and beyond this point both gradually decline.

When 2.00 per cent of chromium has been added to a steel that has a carbon content between 0.75 and 1.50 per cent, it combines great hardness with ability to resist shock. It is one of the best materials for piercing armor plate, and is also used in making projectiles. A chromium content of 3.50 per cent in a tool steel that contains 8.25 per cent of tungsten, gives the steel the well-known property of red

hardness; that is, the hardness is not drawn and the cutting edge is maintained when using the tool at a red heat. A high percentage of chromium is also added to a steel that is forged between layers of wrought iron or soft steel and hardened in water. This is used in safes, vaults, etc., to make them burglar proof, and is also used for plough-shares and similar work.

The presence of nickel in steel is very interesting in its influence, because, as mentioned in the previous chapter, when added in amounts up to 8 per cent, it increases the tensile strength, elastic limit, and elongation. Adding from 8 to 15 per cent of nickel produces a brittleness, and the mechanical properties are not ascertainable by experiment. With 20 per cent nickel a rapid rise in elongation is noticed, which increases very rapidly up to 25 per cent, after which the increase is more slow. Fig. 2 is a diagram from Roberts-Austen's "Metallurgy," which illustrates these points. Nickel sometimes produces in

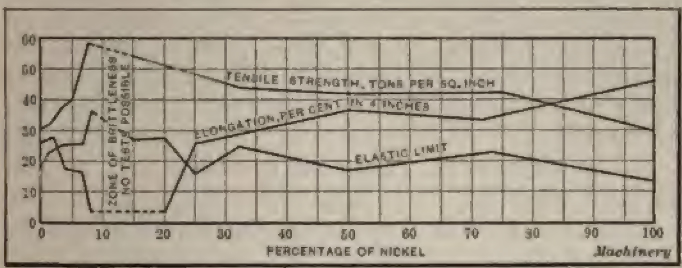

Fig. 2. Diagram Showing Effect of Nickel on Steel

steel a tendency to show laminations and to make it weak at right angles to the direction in which it is rolled. By the addition of chromium these laminations are removed, the metal is given a high degree of homogeneity, and the hardening can be performed more easily and without the danger of fissures appearing.

In nickel steel, the tenacity and elastic limit is much increased by positive quenching up to about 5 per cent nickel, especially with high percentages of carbon. Below 0.50 per cent carbon and 5 per cent nickel the reduction of area remains nearly unchanged, and the elongation but slightly decreases by heat-treatment, but when chromium is added these are both reduced nearly one half by heat-treatment.

Effect of Silicon

Silicon is sometimes used in nickel-chromium steel, as it prevents the formation of blow holes and neutralizes the injurious tendencies of manganese. The majority of these steels, however, do not contain silicon, as its exact influence is not quite clear, and it is difficult to obtain silicon in steel without the presence of maganese. This makes its direct action difficult to determine. In quenching, silicon seems to influence steel the same as carbon in many ways, but this largely depends on the co-existing amount of the latter as well as of man-

ganese. In general, only very small quantities are effective, and then only when the carbon content is low. Silicon will increase the tensile strength, but at the same time lower the elastic limit.

Effect of Manganese

Manganese is always a component of nickel-chromium steel, but over 0.40 per cent is seldom allowed, as a steel high in manganese is difficult to work cold, while otherwise nickel-chromium steel can be bent cold without difficulty. This has been proved by tests; in one case a connecting or piston-rod, after finishing, was bent double and showed no indications of cracks. Another rod was twisted two complete revolutions without injury. When the carbon is less than 0.50 per cent, and from 4 to 6 per cent of manganese is added, steel becomes so brittle that it can be powdered under a hand hammer, but by the addition of twice that amount of manganese the strength is restored. At 15 per cent maganese, again, a decrease in toughness, but not in transverse strength, takes place. With 20 per cent and more of manganese a rapid decrease takes place. The discovery of these properties brought out manganese steel which has some remarkable qualities.. The higher the percentage of carbon, the less manganese is necessary to bring about the result referred to.

Influence of Phosphorus and Sulphur

Phosphorus and sulphur are always components of steel, and probably more time and energy has been spent to get rid of these, or reduce them to a minimum, than on all other experiments. Phosphorus causes a "cold shortness" or brittleness in steel, and almost any quantity is injurious. No matter how high the tensile strength or elastic limit may be made by other components, if the phosphorus content is high, the metal will break when given shock tests. For this reason some object if phosphorus is present in amounts over 0.015 per cent, while others will allow as much as 0.04 per cent before they will agree that it is damaging to any serious extent. A high percentage of sulphur, on the other hand, causes a "hot shortness" or brittleness beyond a dull red heat, and is therefore not desirable when the metal is to be forged or worked hot. This component, however, is not as injurious as phosphorus.

Composition of Nickel-chromium Steels

The different combinations or percentages of the components of nickel-chromium steels are as varied as their makers, but the compositions obtained have resulted in a very high grade of steel. Thus nickel is used in percentages of from 1 to 5; chromium from 0.5 to 5; carbon from 0.25 to 0.45; silicon, when used, from 0.5 to 3; and manganese from 0.25 to 1. Table IV shows some of the nickel-chromium steels that are turned out by the different makers, both foreign and American, and their comparative strength. The first column shows one composition that is comparatively low in nickel and high in chromium, while the next three columns are low in chromium and

high in nickel, other components being about equal. The last two columns contain the specifications that were adopted by the Association of Licensed Automobile Manufacturers. The only difference between them is that one contains 0.45 per cent carbon and the other is 0.25 per cent. The physical characteristics of these two kinds are not derived from actual tests, but are the characteristics which they

TABLE IV. DIFFERENT COMPOSITIONS OF NICKEL-CHROMIUM STEELS AND THEIR STRENGTHS

No. of Sample	Composition in Per Cent						
	Nickel	Chromium	Carbon	Silicon	Manganese	Phosphorus	Sulphur
1	1.60	4.41	0.25	0.20	0.35	0.012	0.018
2	3.30	1.40	0.31	0.20	0.40	0.012	0.028
3	4.40	1.50	0.25	0.24	0.73	0.018	0.012
4	3.50	1.50	0.25	0.25	0.40	0.018	0.022
5	2.09	0.71	0.36	0.21	0.35	0.025	0.026
6	3.38	1.87	0.24	....	0.35	0.028	0.030
7	1.50	0.80	0.25	....	0.40	0.030	0.035
8	1.50	0.80	0.45	....	0.40	0.030	0.035

No. of Sample	Fully Annealed				After Heat-treatment			
	Tensile Strength, Pounds per Square Inch	Elastic Limit, Pounds per Square Inch	Elongation in 2 Inches, Per Cent	Reduction of Area, Per Cent	Tensile Strength, Pounds per Square Inch	Elastic Limit, Pounds per Square Inch	Elongation in 2 Inches, Per Cent	Reduction of Area, Per Cent
1	126,000	115.000	28	64	185,000	160,000	14	48
2	115,000	95,000	24	42	155,000	132,000	8	18
3	......	......	..	..	154,000	138,000	12	45
4	126,000	115,000	28	64	......	......		.
5	112,000	87,000	14	64	......	......		..
6	128,000	80,000	10	58	......	......		
7	85,000	65,000	20	50	180,000	100,000	12	30
8	90,000	65,000	18	35	180,000	140,000	8	30

must possess when a test is made from a 7/8-inch test bar, rolled from every heat and from two separate ingots. The actual tests may show much higher figures, as these are the lowest figures at which the steel will be accepted. The phosphorus and sulphur may, of course, be lower, as the percentage given is the highest that will be allowed. To the tests in this table there should be added a shock test, as all of the tests given might be satisfactory in their results, and yet, if too high in phosphorus, the metal would not stand shocks and torsional stresses.

The steels in the table which are high in carbon are used principally for gears, and are the highest grades of steel in the market, either foreign or domestic, for this purpose. The nickel-chromium steels shown

in the table that contain 0.25 per cent carbon are more extensively used than those with higher carbon content, as they are forged more easily, and are machined and worked with less difficulty. These steels are used where great strength is demanded, combined with a light weight; hence, in automobile construction they are used for such parts as crankshafts, sprocket shafts, rear driving shafts, propeller shafts, axles, wheel pivots, and piston rods. Some racing cars have been built with all the working parts, as well as the frame, of nickel-chromium steel. These nickel-chromium steels are not as readily drop-forged as the ordinary carbon steel, and, therefore, the difference between consecutive die forms should be less than in those used for ordinary steel. In forging, the metal should be heated to about 1380 degrees F., and kept at about that point until the operation is completed. Care must also be taken not to overheat or underwork the metal, as this produces a coarse grain, which will show a low percentage of reduction of area, and the metal will be condemned on account of its inability to withstand the shock stresses. The best forging process is undoubtedly the one using the hydraulic press, as with this the metal is slowly squeezed into the die, thus allowing the mass time to assume its new shape. The formation of crystals will not be able to take place, and the metal will be of a finer grain, with great density, producing less internal stresses and closing up any flaws which might have been in the center of the ingot. In hammer forging, unless the hammer is a large, slow-moving one, only the shell of the forged piece is affected, as the blows will not penetrate to the center.

Heat Treatment

Nickel-chromium steel is nearly always heat-treated, and great care should be used in doing this, as it is very easy to destroy the good qualities of the metal by inferior workmanship in this respect. The factors which influence the results of heat-treatment are:

First: The physical and chemical components of the metal.

Second: The gases and other substances which come in contact with the metal while heating.

Third: The form of the temperature rise curve for each unit of the metal.

Fourth: The highest temperature given to each unit of the metal.

Fifth: The length of time at which the metal is kept at the maximum temperature.

Sixth: The form of the temperature drop curve for each unit of metal.

At about 570 degrees F. most steels lose their ductility and are not capable of resisting the strains of unevenly heated metal. Therefore, the temperature rise curve up to this point should be a gradual one; after this it may be as rapid as possible without overheating. Care must be taken not to overheat or burn the metal, as it is almost impossible to bring it back to its former high standard.

Nickel-chromium steel should be annealed after it has been worked and before heat-treatment, in order that it may return to its natural state of repose, as machining, forging, hammering, etc., is liable to throw it out of its homogeneity. It is annealed in a different manner from the ordinary grades of steel, it being heated to a temperature of about 1470 degrees F., kept at this heat for four hours and then allowed to cool slowly in a slow-cooling furnace, or by packing in ashes or charcoal, the latter being preferred. If carbonizing is resorted to, this steel should be annealed, after carbonizing, as described above.

To harden this steel, it should be heated to about 1470 degrees F. and made as hard as possible by quenching in oil or water, after

TABLE V. CUTTING SPEEDS FOR DIFFERENT GRADES OF STEEL

Depth of cut $\frac{3}{16}$ inch and feed $\frac{1}{16}$ inch

Kind of Steel	Cutting Speed in Feet per Minute	Pounds of Turnings per Hour
Steel with 0.10 per cent of carbon	100	295
Steel with 0.20 per cent of carbon	75	222
Steel with 0 30 per cent of carbon	68	176
Steel with 0.40 per cent of carbon	51	150
Steel with 3.50 per cent of nickel	55	163
0.75 per cent nickel, 0 80 per cent chromium, and 0.25 per cent carbon	50	148
1.50 per cent nickel, 0.80 per cent chromium, and 0.25 per cent carbon	45½	135
Steel with 1 5 per cent nickel, 0 80 per cent chromium, and 0.45 per cent carbon	35	103

Machinery

which it can be drawn to the different degrees required. Gears should be drawn by heating to 480 degrees F. to remove the internal strains. This makes the hardest and toughest gear which it is possible to produce. It will stand an enormous amount of wear and shock stresses, and it is very difficult to break out a tooth with a sledge hammer.

The carbonizing should be done by carefully packing the pieces to be carbonized in a cast-iron pot, in a mixture of powdered bone and charcoal. This should then be heated slowly until the temperature is raised to 660 degrees F., after which the temperature can be raised as fast as desired until 2100 degrees F. has been reached. The steel should be kept at this temperature for at least four hours, after which it should be allowed to cool slowly by taking the pot out of the fire and permitting it to cool without removing the cover. This annealing, tempering, and carbonizing can only be done successfully and with positive assurance by the use of a furnace to which is attached a pyrometer, as the proper degrees of heat cannot be guessed at by the color of the metal.

Machining Nickel-chromium Steel

Nickel-chromium steel is more difficult to machine than ordinary steel, and can only be done successfully when it is fully annealed and with high-speed tool steel. Under these conditions it should be cut at the rate of 35 feet per minute, the cut being 3/16 inch deep, with 1/16-inch feed. The comparison between the machining of this and other steels is best illustrated by Table V.

This steel is only used where strength and lightness are more important than cost. In automobile construction, it is only used on the higher priced cars and for the parts which have to stand the largest amount of strains and stresses. Its ability to stand these stresses better than the ordinary carbon steel was demonstrated by one motor car builder, by taking two round bars 1⅛ inch in diameter, one of which was nickel-chromium steel and the other a mild carbon steel, fairly low in carbon, gripping both ends, leaving 9½ inches exposed and subjecting them to a bending operation, the bending being 9/32 inch out of the true position of the center-line of the bars. This bending was made, back and forth, with the carbon steel bar 20,000 times before it fractured, while with the nickel-chromium steel bar 250,000 bendings were made before this fractured. Other tests which have been made show similar results.

With the continued use of this grade of steel, its manufacture in larger quantities by the steel makers, and the improvements in machinery and cutting steels, it will no doubt be cheapened both in the production and in its manufacture into finished products, so that its use can become more diversified, and better wearing qualities, lighter weight and greater strength given to the working parts of many classes of machinery.

CHAPTER III

VANADIUM STEEL

Among the many new alloy steels which have been brought out in the last few years, the vanadium steels constitute one of the latest additions. These steels, in many different percentages of alloy, have been given numerous tests in order to determine the qualities of the steel and its action when submitted to the various strains and stresses it is liable to meet when put into actual use. These tests would seem to place it in the front rank of high-grade alloy steels, although it will be, after all, the actual use of this steel for the moving parts of machinery that will demonstrate to a certainty its wearing qualities, as well as its ability to withstand strains and stresses.

The mechanical engineers of the present day have been forced to become better metallurgists than they ever were in the past, in order to intelligently design high-grade machinery, as the so-called "mysterious" failures of steels are becoming more numerous and more pronounced every day. These failures of steel, which occur in high-grade alloys the same as in the Bessemer steel rails, although not as frequently, have proved to the engineers of to-day that the old custom of judging a steel by its resistance to static load and the amount it would stretch under that load is not always to be depended upon. The uses to which steel is put call upon it to resist strains applied in a totally different manner to that under which it was tested by simply pulling a bar until it broke.

In machine construction, those parts which are liable to failure while in use require high dynamic qualities, that is, resistance to repeated stresses, alternating stresses, simple repeated or alternating impacts, and fatigue, the latter being the outward and visible sign of the inter-molecular vibratory deterioration. Thus a new field is being opened out, and while vanadium affects steel in a manner that tends to increase the static strength, it also raises the dynamic properties to a very remarkable extent. Some recent tests of armor plate, made by the United States Government, give an illustration of this. In the past it has been the custom to make armor plate as hard as possible, and at the same time retain a high degree of strength. For this reason chromium was used as the principal alloy, and in many cases the only alloy, as it gave steel a hardness that was not obtainable in any other way. In the recent test spoken of, a vanadium-chrome steel was used with a hard outer shell and a very soft core, similar to the condition obtained by carbonizing. The result was that it withstood a much higher test of the impact blows delivered by the shots from a gun than the hard steels formerly used.

Vanadium and its Influence on Steel

In an article in MACHINERY, May, 1911, Mr. William B. Snow gives a brief review of the main characteristics of vanadium and vanadium steel. Although vanadium has been used to a considerable extent for a number of years as an alloy for steel, one frequently hears the question asked: "What is vanadium, and how do vanadium steels differ from other steels?" Vanadium is an element, the existence of which was first recognized by a Mexican, Del Rio, about the year 1800. A number of years later it was discovered that the remarkable qualities of Swedish iron were due to the presence of a small amount of vanadium in the native ore. It is only quite recently, however, that vanadium has been found in sufficient quantities for commercial use.

Pure vanadium is silvery white in appearance, and of very high melting point. In the pure state it has little or no practical application; for use as an alloy it comes in the form of ferro-vanadium, which usually contains from 30 to 40 per cent of vanadium. Vanadium is such a powerful alloy that it only needs to be used in exceedingly homeopathic doses to produce marked results. The use of as small an amount as 0.05 per cent of vanadium produces a strong scavenging action that indirectly toughens the steel to a most noticeable extent, by removing the oxide, nitrides, etc. The use of a larger amount—0.18 per cent, or more—causes a portion of the vanadium to combine with the ferrite or free carbonless iron in the steel, thereby directly toughening it.

Vanadium is very volatile in its action, and considerable difficulty is experienced in getting it to mix thoroughly and evenly with the steel. When put into crucible steels it has a particularly aggravating tendency to go to the bottom of the pot in a lump, where it is frequently found after pouring. The higher the percentage of the vanadium, the greater the difficulty experienced in getting it to mix properly with the steel. It is practically impossible to put over 1.25 per cent of vanadium into steel and keep it there, while most vanadium steels do not contain more than 0.25 to 0.30 per cent of vanadium.

In order to more fully understand its specific action, consider briefly what takes place when vanadium is put into steel. Steel consists of iron, with more or less carbon, sulphur, phosphorus, manganese, silicon, and, frequently, chromium and nickel. The carbon contained is combined chemically with a molecular portion of the iron. A molecule of this chemical compound alloys itself with twenty-one atoms of carbonless iron and the resultant alloy is distributed in spots, or patches, through the carbonless iron. This alloy is known technically as pearlite, and the free carbonless iron as ferrite. Part of the manganese unites chemically with the sulphur in the steel, forming striæ, or globules throughout the mass. The phosphorus and the silicon, also the larger part of the nickel—if used—are dissolved in the ferrite in what is known as "solid solution." The chromium is found as a constituent of the pearlite. When vanadium in a sufficient amount is used, it goes into solid solution, partly in the

ferrite, which it toughens, and partly in the carbide portion of the pearlite, which it strengthens.

Vanadium is also beneficial to steel in still another way, its use securing better results from the process of annealing, as will be seen from the following: When heat is applied to a bar of steel, as in annealing, it becomes sensibly hotter with each degree of heat applied, up to a certain point, known as the point of decalescence. When the steel reaches this point, further application of heat does not increase the sensible temperature, but instead, a change takes place in the steel itself; the pearlite becomes broken up, its carbides going

Fig. 3. Axle Steel Samples showing Difference in Physical Qualities. Length, 52 inches; Depth, 2 inches; Width, 1½ inch; Thickness of Flanges, 3/16 inch at Edge; 3/8 inch at Web; Thickness of Web, 3/16 inch

into solid solution in the ferrite. When this change is completed, the sensible temperature of the steel again rises. In cooling, the reverse takes place; to a certain point, known as the point of recalescence, the steel cools regularly, then it apparently ceases to cool, and a change takes place in the steel itself. The dissolved carbides are thrown out of solution, and alloy themselves with the ferrite to re-form pearlite. When this change is completed, sensible cooling again proceeds.

Since the object of annealing is to break up the carbide areas and distribute them in small colonies, the steel is heated above the decalescence point, the temperature being maintained long enough to thoroughly decompose the pearlite—as well as to remove any mechanical strains that may have been locked up in the mass by previ-

ous manipulation under hammer and rolls. It is then cooled slowly through the recalescence point, care being taken to prevent chilling.

As a vanadium ferrite does not permit of the ready passage through it of the carbides re-precipitated at the recalescence point, the distribution of the carbides in a vanadium steel is remarkably even. This greatly increases the toughness and tenacity of the steel, in addition to the greater toughness already obtained with the background of vanadium ferrite (the portion of the vanadium that has gone into solid solution with the free carbonless iron).

Properties of Vanadium Steel

The peculiar properties of vanadium steel are best shown by the following comparative table of the physical properties of vanadium and other crucible steels:

Condition of Steel—Natural, as rolled	Tensile Strength, Pounds per Square Inch	Elastic Limit, Pounds per Square Inch
Carbon Steel	82,300	56,000
Chrome-nickel Steel	102,100	69,230
Chrome-nickel-vanadium Steel	118,100	87,500
Chrome-vanadium Steel	153,220	98,560
Condition of Steel—Annealed		
Carbon Steel	61,100	43,200
Chrome-nickel Steel	81,200	56,700
Chrome-nickel-vanadium Steel	96,350	69,300
Chrome-vanadium Steel	112,000	76,160
Condition of Steel—Oil tempered at 1500 deg., F., drawn to 600 deg. F.		
Carbon Steel	126,300	101,100
Chrome-nickel Steel	150,300	134,500
Chrome-nickel-vanadium Steel	163,700	152,300
Chrome-vanadium Steel	233,090	210,500

From the above table it is seen that the two most marked characteristics of vanadium steel are its high tensile strength (breaking point), and its high elastic limit (stretching point). Another equally important characteristic is its great resistance to shocks; vanadium steel is essentially a non-fatigue metal, and therefore does not become crystallized and break under repeated shocks like other steels. Tests of the various spring steels show that when subjected to successive shocks for a considerable length of time, a crucible carbon steel spring was broken by 125,000 alternations of the testing machine, while a chrome-vanadium steel spring withstood 5,000,000 alternations, remaining unbroken.

Another characteristic of vanadium steel is its great ductility. Highly tempered vanadium steel springs may be bent sharply, in the cold state, to an angle of 90 degrees or more, and even straightened again, cold, without sign of fracture; vanadium steel shafts and axles may be twisted right around several complete turns, in the cold state, without fracture. This property, combined with its great tensile strength,

makes vanadium steel highly desirable for this class of work, as well as for gears which are subjected to heavy strains or shocks upon the teeth.

In the matter of heat-treatment, vanadium steels will stand a wider variation of temperature without detrimental effect than other steels. One particular characteristic of vanadium steel is the evenness with which is hardens. Vanadium steels forge readily, and, in the annealed state, are no harder to machine than an ordinary steel containing the same percentage of carbon. In this respect they differ greatly from other steels of high tensile strength, in which the presence of a considerable amount of nickel renders machining extremely difficult.

The usefulness of vanadium as an alloy is not confined to steel alone; it is equally beneficial to other metals. Cast iron, brass and copper are much improved by the addition of a small percentage of vanadium, their strength and endurance being greatly increased. Castings from these metals show a finer grain and greater freedom from porousness through the use of vanadium. Aluminum, a particularly difficult metal to machine, is greatly benefited in this respect by the addition of vanadium, which not only renders it easier to work, but also insures its ready flow in the mold, producing sharp, even castings from difficult shapes.

The Practical Advantages of Vanadium in Steel

Vanadium, as mentioned, acts as a purifier on the metal, and very small percentages give the desired results; but if used in too large a percentage, it will spoil the metal. Sometimes the vanadium will perform this purifying action and leave but a trace to show on analyzing the steel, but in the majority of instances it stays in the metal. Vanadium steel, however, is the most difficult of all the alloy steels for the chemist to correctly analyze.

Vanadium has the property of elusiveness to a very marked degree, and must be handled by the steel maker very carefully in order to get the necessary results. It is, therefore, marketed in the form of ferro vanadium in the proportions of about two parts of iron to one part vanadium. For machinery purposes it is generally alloyed with steel in percentages of from 0.10 to 0.30 per cent, but it has been tried as a tool steel with as high as 3 per cent, and when this was compared with a 3 per cent tungsten tool steel by cutting a chilled white iron plate, and then collecting and weighing the cuttings, the vanadium tool steel was found to excel the tungsten tool steel by 25 per cent. It is used in manufacturing a tool steel by one steel maker, in this country, who uses vanadium in a small percentage, tungsten in a large percentage, chromium in a small percentage, and a few other ingredients in small percentages, and the results obtained from this steel show that it excels other tool steels by from 10 to [illegible] per cent in their cutting qualities.

Vanadium is not like nickel, chromium, [illegible] and other mineral elements used in high grade steel making [illegible] it [illegible]

within itself no virtues, except in its action as a purifier on the other elements. Its most successful application lies in the direction of steels such as chrome-vanadium or nickel-vanadium. In a technical sense it retards the segregation of the carbides, thereby producing in steel a high degree of homogeneity and a grain of great uniformity and fine texture. In retarding the segregation of the carbides, vanadium renders steel susceptible to great improvements by heat-treatment or tempering, and in this manner the steel can be prepared to resist wear and erosion. It also renders possible the natural formation of the "sorbitic" structure which is necessary in metals which have to withstand wear and erosion. Vanadium steel also has self-lubricating properties to a greater extent than other high-grade steels, hence it is more valuable for shafts running in bearings and for gears. It also produces soundness mechanically as well as chemically

TABLE VI.

Specimen	Tensile Strength in pounds per square inch	Elastic Limit in pounds per square inch	Elongation in 2 inches, per cent	Reduction of Area, per cent
A	82,500	50,000	30	66
B	116,000	90,000	21	71
C	165,000	147,000	11	61
D	165,000	147,000	16	59
E	200,000	185,000	11	56
F	228,375	......	..	..
G	198,750	190,000	9	34

and toughens the steel, thus conferring great powers of resistance to torsional rupture.

Chromium gives to steel a brittle hardness which makes it very difficult to forge, machine or work, but vanadium, when added to chrome-steel, reduces this brittle hardness to such an extent that it can be machined as readily as a 0.40 per cent carbon steel, and it forges so much more easily that the Ford front axle—shown twisted in Fig. 3—which is 52 inches long, 2 inches deep, of I-beam section, with the web only 3/16 inch thick, is being forged in three heats. The first heat is used to forge the straight I-beam part; the second heat is used to forge the arm for the steering-rod connection and the projections for the steering pivot on one end, while the third heat is required to forge the same on the other end of the axle. Automobile axles of similar design, when formed out of chrome-nickel steel, require from 15 to 20 heats to give them the proper shape, and even then the dies give a great deal of trouble. For this reason the nickel or chrome-nickel axles are usually forged in two halves, and welded together in the center by the electric welding process.

That vanadium steel can be machined as easily as ordinary carbon steel, that is, running at the same speed and using high-speed tools, is testified by the Ford Motor Co.: "We find in actual practice that vanadium steel costs no more than ordinary carbon steel and vastly less than nickel, because of the saving in machining, forging and

tempering, and the greater accuracy we are able to obtain, owing to uniformity of metal and the lighter weight of metal we are capable of using, owing to its great strength."

Fig. 3 shows the comparative amounts of torsion which vanadium and some other steels will stand by twisting. Table VI. gives results of tests on various kinds of steel. *A* is a 0.06 per cent carbon steel, heat-treated. *B* is a 0.07 per cent nickel steel, heat-treated. The others are all taken from the same bar of vanadium steel and subjected to different degrees of heat-treatment. *F* merely shows the ultimate strength obtainable.

TABLE VII.

Specimen	Tensile Strength in pounds per square inch	Elastic Limit in pounds per square inch	Elongation in 2 inches, per cent	Reduction of Area, per cent
1	88,000	64,500	29	59
2	98,750	67,500	25	77
3	127,500	110,000	14	59
4	147,000	140,750	17	57
5	165,000	155,000	16	55
6	176,500	175,000	7	27

Vanadium steel can also be given a wide range of strengths together with hardness or softness by properly heat-treating. This is best shown by the accompanying Table VII. of test bars which were pulled on an Olsen testing machine by the Ford Motor Co. The test bars were all made out of one bar of steel. Specimens 1 and 2 are in their softest condition; specimen 3 is in the condition of an axle; specimens 4 and 5 are in the crankshaft condition; and specimen 6 is in a mesh gear condition. Other tests have shown much higher strengths, but the remarkable features of these tests are the way the elastic limit has been brought up nearly to the tensile strength, and the high reduction of area.

TABLE VIII.

Kind of Steel	Pendulum Impact, Foot-pounds	Alternating Impact, Number of Stresses	Falling Weight on Notched Bar, Number of Blows	Rotary Vibrations, Number of Revolutions
Carbon axle stock	12.3	960	25	6,200
Nickel axle stock	14.0	800	35	10,000
Vanadium axle stock	16.5	2700	69	67,500
Vanadium crankshaft stock	12.0	1850	76	.....
Vanadium mesh gear stock	6.0	800	..	.....

While the static strengths before stated are and can be made the equal of almost any alloy steel, it is in the dynamic properties that vanadium steel excels all others, and these are becoming more and more the real tests of steel for use in moving machinery or where strains other than a direct pull are put upon it. These properties of vanadium steel as compared with carbon and nickel steel are shown by the tests given in the accompanying Table VIII.

CHAPTER IV

MANGANESE STEEL

The following information on the subject of manganese steel is, mainly, abstracted from a paper by Mr. F. E. Johnson, read before the Association of Engineering Societies, October 21, 1910.

Manganese steel was first successfully produced by the Hadfields in England about thirty years ago, and was known as "Hadfield steel." It was first made in the United States by the Taylor Iron & Steel Co., of High Bridge, N. J. About 1905 other foundries in this country took up its production, but they soon discovered that it was a very difficult metal to produce successfully, and comparatively few foundries are today engaged in manganese-steel making. In fact, the manufacture in the United States is almost entirely confined to two companies, the one mentioned above, and the Edgar Allen American Manganese Steel Co. The latter firm has two foundries, one at Chicago Heights, Ill., and one at Newcastle, Del.

We might define manganese steel as a metal of the following composition:

	Per Cent
Manganese	11.00 to 15.00
Carbon	1.00 to 1.20
Silicon	0.25 to 0.40
Phosphorus	0.06 to 0.11
Sulphur	0.02 to 0.06
Balance, iron.	

Variations from the composition given above have been tried, and steel has been made containing anywhere from 8 to 35 per cent of manganese, but commercial manganese steel contains at present about 10 to 15 per cent of manganese and 1 per cent of carbon, these two constituents being the chief factors in manganese-steel making. Great care must be exercised in the manufacture so that the percentages of these two constituents are in the right proportion. Too much carbon and not enough manganese makes the steel brittle.

Manganese steel is considered a very hard metal, because of the fact that it cannot be machined as readily as ordinary iron or steel. In fact, it is practically impossible to machine it with even the highest quality of tool steel. Tests made on the scleroscope indicate a hardness of about 30 for Bessemer steel, from 40 to 50 for manganese steel, and from 65 to 70 for chilled cast iron; yet it has been demonstrated again and again that manganese steel will outwear chilled cast iron many times over. In general, it is safe to say that it will wear from four to eight times as long, depending upon the purpose it is used for and the conditions under which it works. The secret of the resist-

ance of manganese steel to abrasive action seems to be due to its ability to "flow" or endure repeated distortion. Under abrasive action it simply moves away from one place to another, but does not actually wear off. One can take, for example, a square corner of a piece of manganese steel and peen it over, and then pound it back to a square corner, and keep up this operation without actually being able to remove any material.

Manganese steel is very sensitive to heat. A statement given out by the Edgar Allen American Manganese Steel Co. contains some interesting information on this point. Manganese-steel castings should never be heated, because if heated to a temperature of only 400 degrees F., they will lose their toughness and strength to a remarkable degree. This applies to castings of plain design; castings of irregular design do not even stand as high a heat as 400 degrees F. A casting which is in perfect condition and free from internal stresses at the time it leaves the foundry is very likely to break or crack if heated. The company strongly disclaims any responsibility for the breakage of any manganese-steel castings which have been heated after their shipment from the company's foundry.

Manganese steel will not become a permanent magnet; hence it is used for disks in magnetic hoists, as the smallest particle of iron or steel will not cling to it after the current is shut off. The tensile strength of early specimens, determined by Hadfield in England, was 150,000 pounds per square inch, with an elongation as high as 50 per cent. The average commercial steel of today, however, has a tensile strength of 82,000 pounds per square inch, an elastic limit of 45,000 pounds and an elongation of 30 per cent. Forged manganese steel will give better results, but there is very little commercial forged manganese steel made at this time.

Manufacture of Manganese Steel

The manufacture of manganese steel is carried on with a great degree of secrecy, and for this reason full information on some of the processes employed cannot be given. The steel is composed chiefly of a mixture of scrap iron and pig, this mixture being very carefully made up according to the predetermined composition of the steel. The mixture is melted in an ordinary cupola such as is used in any foundry, and is then run into a converter and blown quite similarly to Bessemer steel. This process, however, is carried out with great care and is directed by one man only, who operates everything from the central station or platform close to the converters. After the steel is blown, it is poured into large ladles from which the slag is removed. The manganese, which has previously been melted in graphite crucibles under intense heat, is then added. From the large ladles it is poured into sand molds which are practically the same as ordinary molds for cast iron.

One difficulty with manganese-steel castings is the excessive shrinkage when cooling. Manganese steel shrinks 5/16 inch per foot, which

is nearly three times as much as the shrinkage of ordinary cast iron. All ladles and molds are kept very hot so as not to chill the metal before it is poured, as in this case a homogeneous casting could not be produced. After the casting process is completed, the castings are all subjected to a heat-treatment, or both heat-treatment and water submergence. This part of the process is kept secret by the manufacturers.

Manganese-steel castings can only be successfully made to certain sizes as regards length and particularly as regards cross-sectional area, the thickness being the prime factor. The greatest thickness of any section that has been successfully cast, up to date, is about 4½ inches. It is also very difficult to cast small or thin sections, the lower limit being about ⅝ inch for ordinary castings. The reason that the thickness is so important is because of the after treatment, which apparently will only penetrate to a certain depth. Thin sections are limited by the flow of the metal.

Owing to the fact that manganese steel cannot be cut by ordinary cutting tools, all machining on manganese-steel castings must be done by means of grinding. Sometimes steel bushings and other pieces of ordinary soft steel are inserted in the molds and cast into the casting, making it possible to bore out, drill or tap the casting at certain places. For example, the hubs for car wheels may be provided with soft steel bushings, and soft steel inserts may be provided for set-screws, etc.

Uses for Manganese Steel

The uses of manganese steel are not very extensive at present, due partly to its high first cost, and partly to the difficulty of machining the steel. It is used mostly for castings subjected to heavy strains and shocks and excessive wear, such as the wearing parts of steam shovels, ore and rock crushers, mining machinery, etc. It is also used to a considerable extent for safes. When rolled and forged, it is used for rails, frogs and crossings. The use of manganese steel has made it possible to cut down the maintenance cost for many machines very materially.

It may be of interest to emphasize the fact that manganese steel has proved itself efficient when used in cases where it is subjected to shocks. An idea prevails among railway engineers that this steel will not stand shocks. As an experiment, therefore, a manganese-steel frog weighing 800 pounds was bent under a drop weight. The frog was subjected to 165 blows from a weight ranging from 1250 to 2500 pounds and falling from a height varying from 3 to 23 feet, the total energy exerted being nearly 1,700,000 foot-pounds. No fracture or impairment of any nature could be discovered. There are hundreds of manganese-steel frogs and cross-overs now in use. At the Northwestern Terminal, in Chicago alone, there are 200 frogs of this kind installed.

CHAPTER V

TITANIUM STEEL

Titanium is one of the elements that have been successfully used to improve the quality of steels. It has also been very successfully used for cast iron and for some of the non-ferrous metals. The first heat of titanium steel made in America was poured in 1907, and since that time a great deal of investigation has been conducted and many experiments have been made. These tests have shown that when ferro-titanium has been added to steel or iron in very small quantities, it has greatly strengthened these metals and improved their qualities in other ways; it can now be considered one of the best of purifying elements that have been used in the manufacture of steel.

Titanium belongs to the same chemical group as silicon, and three other elements that are quite rare. It forms a compound with oxygen, called titanium dioxide (TiO_2), occurring in nature in three distinct forms, the principal one being the titaniferous iron ore so often encountered. In some respects it resembles carbon. Like many of the other elements, it is very difficult to control and make use of when a natural ingredient of the iron ores; it is therefore necessary to separate it in the electric furnace and manufacture it into ferro-titanium containing from 12 to 15 per cent titanium, about 6 per cent of carbon and 5 per cent of all other impurities, with the balance iron. This, when correctly added to steel or iron, can be made very beneficial. With this percentage of titanium, it enters into almost instant solution; but as titanium has a much higher melting point than iron, a higher percentage would cause the titanium to segregate and no beneficial results would be obtained.

While nickel, chromium, molybdenum and tungsten add certain good qualities to steel, none of these combines with nitrogen, thus removing it from the metal, in the way titanium does. Its combination with nitrogen gas takes place with the evolution of heat, and it is the only undisputed example of the combustion of an element in nitrogen. When heated in oxygen it creates an instantaneous dazzling flame.

That oxygen and nitrogen are very injurious to steel and decrease its strength, wearing qualities, etc., is now a recognized fact; that these elements are present in larger quantities than has been previously supposed is also recognized. When titanium is added to the molten metal, it combines with these gases, which otherwise are liable to become occluded in the steel, and carries them off into the slag. These gases also form miniature bubbles that, when segregated, form holes large enough to be plainly seen. If segregated in large enough masses they form good-sized blow-holes.

Oxide forms when oxygen comes in contact with iron, and is present in very small black specks throughout the steel. This oxide can only

be seen when the surface has been perfectly polished and magnified at least 1000 times. It is invariably found in steels that produce blisters when pickling, and this leads to the conclusion that the blisters are formed by the reduction of oxide by the hydrogen evolved during the pickling process. High-carbon steel rods that contain the same impurities occasionally fracture in the pickling bath, and doubtless the same pressure that blows a blister in mild steel will cause a rupture in hard steel.

Owing to the gaseous nature of both oxygen and nitrogen, it has been difficult to analyze steels for these contents. Some recent investigations, however, showed that the percentage of oxygen in some twenty-four samples of steel ranged from 0.021 to 0.046 per cent. These percentages may seem to be so extremely small that they could be ignored. But the amount of an element present, however, should not alone be considered, when judging its influence on steel; the combinations that the element forms should be taken into consideration. When mention is made of 0.05 per cent of sulphur, it is in reality the 0.13 per cent of manganese sulphide that affects the quality of the metal. Oxygen has only half the atomic weight of sulphur and is capable of forming larger quantities of compounds; therefore, it exerts a greater influence. Thus where 0.05 per cent of sulphur corresponds to 0.13 per cent of manganese sulphide, 0.05 per cent of oxygen corresponds to 0.22 per cent of ferrous oxide. This percentage is therefore high enough to very materially affect the qualities of steel.

Influence of Nitrogen on Steel

It has been shown by some recent investigations that, at first, an increase of nitrogen causes the toughness of steel to slightly increase, but reduces its ductility; each increase of nitrogen causes the elongation to rapidly diminish. Steel with 0.5 per cent carbon loses its ductility in the presence of 0.040 to 0.047 per cent of nitrogen. In a one per cent carbon steel, the elongation and contraction become nil when the nitrogen content reaches 0.030 to 0.035 per cent. In the softer steels, this happens when the nitrogen content reaches 0.050 to 0.065 per cent, and in the very soft steels, with about 0.08 per cent of nitrogen.

Open-hearth steel usually contains from 0.020 to 0.025 per cent of nitrogen; Bessemer steel from 0.018 to 0.062 per cent; and crucible steel runs from 0.010 to 0.015 per cent in nitrogen. Thus, a nitrogen content of at least 0.012 per cent must nearly always be reckoned with. Steels made in the resistance electric furnace are an exception to this, as they are practically free from nitrogen. Steels, however, that are made in the arc electric furnaces, in the presence of basic slags, are liable to contain injurious amounts of nitrogen.

Titanium has a very strong affinity for both oxygen and nitrogen; it forms with oxygen an oxide, and with nitrogen, a stable nitride that shows as tiny red crystals under the microscope. Both of these are then carried off into the slag and the quantity of slag that is lifted

from the molten metal is quite materially increased. The deoxidation of steel is usually accomplished with manganese and silicon, but these never remove the oxides as thoroughly as is desired. Titanium is a much more powerful deoxidizer than either or both of these; when added to steel at the time of tapping, it completes their unfinished work and reduces the oxygen and nitrogen to mere traces. If a greater amount of titanium is used than is needed to remove the oxides and nitrides, it will afterward attack the sulphur and phosphorus and if it does not remove them, it counteracts their injurious effects upon the steel. The phosphorus may be made to pass into the slag as phosphate of titanium by using special means. The reaction of titanium on the sulphur has a tendency to carry it off in the form of a sulphide or sulpho-cyanide of titanium. Cupro-ammonium etching tests show the low sulphur and phosphorus content of titanium-treated steel. The very energetic reaction of the titanium and nitrogen takes place at a temperature of about 1475 degrees F. The good effects of their union can easily be lessened by a careless shutting off of air, thus permitting the formation of titanium and nitrogen combinations that are of no value.

How easily nitrogen finds its way into steel is shown by a heat of Bessemer steel that had been over-blown three minutes. This was found to contain 0.032 per cent of nitrogen, whereas the normal steel contained only from 0.012 to 0.022 per cent. Another heat of Bessemer steel containing from 0.013 to 0.014 per cent of nitrogen was treated with one per cent of titanium and this reduced the nitrogen to from 0.004 to 0.005 per cent.

Method of Adding Titanium

When possible, it is always best to add the ferro-titanium to the steel while it is being tapped into the ladle, and after the ferro-manganese has been added. It is lighter than iron and would not sink and disseminate if it were added near the top; hence, it should be shoveled in gradually while the steel is flowing into the ladle. Titanium-treated steels should be held in the ladle for from 5 to 15 minutes before pouring, in order to allow the titanium to do its work and scavenge out the oxygen and nitrogen. It is difficult to influence steel makers to hold the steel that long in the ladle, as without the titanium it would become chilled in a much shorter time. Titanium, however, raises the temperature and the metal is in better condition for pouring after standing than before. Owing to an accident, one ladle had to be held 20 minutes after tapping and adding the titanium and it was then found to be in better condition for teeming into ingots than the ordinary steel that is teemed as soon as the ladle is filled. This is a statement that is very difficult to make steel makers believe; but the evidence is very conclusive and can easily be obtained.

When commencing the use of titanium, one per cent should be added to the bath; this can gradually be reduced until the beneficial results obtained reach the high point and begin to diminish. In most

cases one-half of one per cent is all that can be made to benefit the metal. In manufacturing Bessemer steel rails, this latter percentage only increases their cost about $1.50 per ton. It is antagonistic to aluminum and the two should never be used together, for aluminum adds brittleness to steel, while titanium removes brittleness.

By removing the oxygen and nitrogen, titanium prevents the formation of blow-holes in steel. This is well illustrated by the two pieces shown in Fig. 4. The one containing blow-holes was cast without any titanium, while the piece without blow-holes was cast from the same metal after 0.5 per cent of titanium had been added. The reaction of the titanium raises the temperature of the bath and makes it more liquid by freeing it from the free oxide and slag. This allows the metal to subside in the mold while cooling and the pipe is smaller

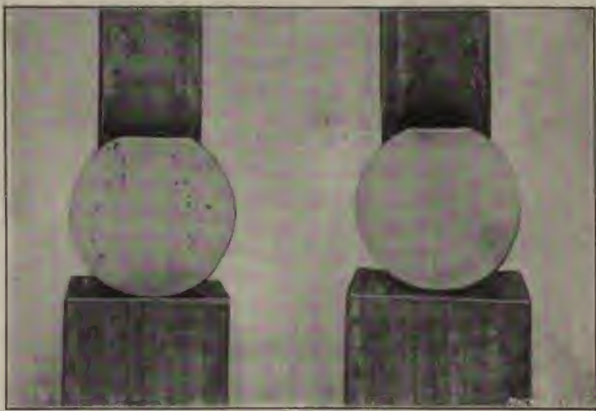

Fig. 4. Blow-holes removed from Cast Iron by Titanium

and flatter. The metal invariably lies dead in the ingot molds and does not boil. By removing the occluded gases and slag from steel, titanium increases the density of the metal and retards any tendency towards segregation, thus making a much more homogeneous metal. It also increases the tensile strength, elastic limit, contraction, transverse strength and ductility of steel. It greatly improves its resistance to frictional or abrasive wear, and resistance to shock, torsional and impact strains.

Tests of Titanium Steel

One example of the ability of titanium steel to withstand torsional strains was obtained by twisting through seven complete revolutions a bar four feet long and one and one-eighth inch square; there was no sign of a fracture. The Brinell hardness test shows a titanium-treated steel to be softer than one not treated with titanium.

One recent test of some structural steel showed that before it was treated with titanium, it had a tensile strength of 67,000 pounds per square inch and an elastic limit of 42,000 pounds, the elongation being

24 per cent, and the contraction, 40 per cent. After this same metal had been treated with 0.50 per cent of titanium, the tensile strength was 77,120 pounds per square inch, the elastic limit, 51,750 pounds, the elongation, 25 per cent, and the contraction, 43 per cent.

Another heat of steel that was rolled into billets and then into iron rods of slightly less than ¼ inch diameter, had a tensile strength of 114,400 pounds per square inch, an elastic limit of 91,000 pounds per square inch, an elongation of 28 per cent, and a contraction of 52 per cent; ordinarily, 90,000 to 95,000 pounds per square inch is the tensile strength of this metal. This 20 per cent increase in tensile strength was doubtless due to the titanium removing the occluded gases and slag.

The resistance of titanium steel to abrasive or frictional wear is well shown by comparing the steel rails illustrated by Figs. 5 and 6. In

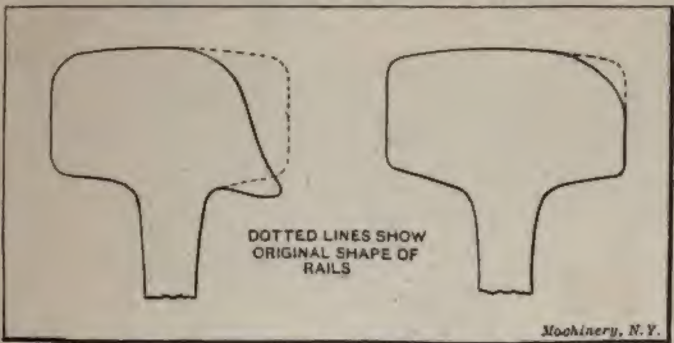

Fig. 5. Ordinary Bessemer Rail Showing Wear in Nine Months

Fig. 6. Titanium-treated Bessemer Rail Exposed to Same Amount of Wear

Fig. 5 is shown an ordinary Bessemer rail that was laid October 7, 1909, and measured July 8, 1910, to get the shape as shown and thus show the amount of wear. Fig. 6 shows the shape of a titanium treated Bessemer rail that was laid next to that shown in Fig. 5 on the same date and measured on the same date. The ordinary Bessemer rail lost 7.03 pounds per yard during the 9-month wear, while the titanium treated rail only lost 1.39 pound per yard. Another method of testing for abrasive wear is performed with the machine shown in Fig. 7. This shows a section of a steel rail placed upon the top of a revolving plate, coated with abrasives, and held down by a lever. On the handle of this lever a block of iron of known weight is hung, as shown.

Titanium treated steels have recently been extensively tried for gears, plates, rolls, tires, castings, etc., and have almost invariably shown a reduction of brittleness and an increase of durability. One method of testing this is by the machine shown in Fig. 8. In this, bar *A* is held in the machine and bent around a 1-, 2- or 3-inch center, as the case may be, located at *B*. Different sized centers are shown at *C*, *D* and *E*.

Fig. 7. Testing Rail Section for Abrasive Wear, in a Special Machine

Fig. 8. Machine for Making Bending Test on Titanium-steel Bars

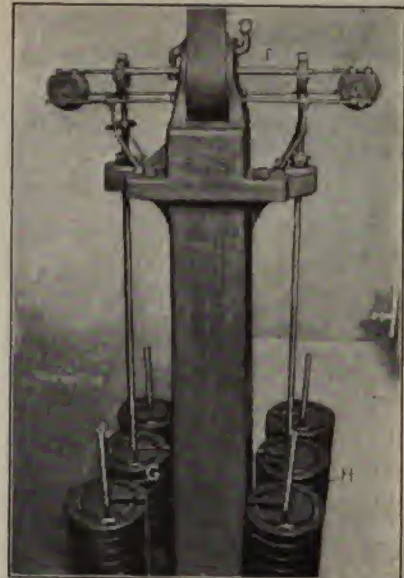

Fig. 9. Testing Endurance of Titanium Steel in a White-Souther Rotary Vibrational Testing Machine

A steel that contained 0.25 per cent of carbon, 0.30 per cent manganese, 0.40 per cent silicon, 0.04 per cent phosphorus, and 0.03 per cent of sulphur, would frequently crack in many directions when forged under a hammer at a bright red heat. When this same steel was treated with 0.030 per cent of titanium it worked down smoothly and evenly without a flaw. Good results might be obtained if the manganese and silicon were reduced by nearly 50 per cent

and the sulphur and phosphorus slightly increased, the effect of the titanium remaining practically the same as before.

The endurance of titanium treated steel has been well demonstrated by tests that were given it on the White-Souther rotary vibrational testing machine shown in Fig. 9. An open-hearth steel that contained 0.25 per cent carbon, 0.64 per cent manganese, 0.425 per cent silicon, 0.04 per cent phosphorus, and 0.035 per cent sulphur, withstood 2,660,000 revolutions at a fiber stress of 38,870 pounds. After this same steel had been treated with titanium, it was given 4,052,200 revolutions at the same fiber stress, namely, 38,870 pounds. The stress was then increased to 40,600 pounds and the piece stood 10,800,700

TABLE IX. DROP TESTS OF RAILS

Number of Drop				
1	2	3	4	5
Deflection in Inches			Condition	
1.3	2.5	3.5	Straight	Broke
1.4	2.5	3.6	Straight	Broke
1.4	2.6	3.9	Straight	Broke
1.5	2.7	4.0	Bent other way	As before
1.5	2.1	4.1	Straight	Broke
1.5	2.1	4.1	Broke	....
1.4	2.7	3.1	Straight	Quite straight
1.4	2.7	4.1	Straight	Broke
1.4	2.2	3.4	Straight	Broke
1.5	2.7	3.9	Straight	Quite straight
1.6	2.9	4.1	Straight	Flange broke
1.6	3.1	4.4	Bent	Flange broke
1.6	3.1	4.2	Bent	Flange broke

Machinery

additional revolutions without a fracture. The fiber stress was again increased to 42,400 pounds and the piece given 1,918,600 more revolutions. The stress was increased a third time to 44,200 pounds and the piece was given an additional 1,006,300 revolutions before it broke. This was a total of 18,274,900 revolutions for the titanium steel, many of which were given it at an increase of fiber stress, as against 2,660,000 revolutions for the untreated steel.

For these tests a bar is placed in the machine as shown at *F*, and revolved by the belt and pulley while the weights located at *G* and *H* produce the fiber stress. As it is well known that iron is ductile in proportion to its purity, this increase in rotary vibrational strains can only be attributed to the purifying properties of the titanium which by removing the oxygen, nitrogen, etc., increases the cohesive force between the molecules and makes the steel more homogeneous. In increasing the ductility it does not soften the metal enough to weaken it, but on the contrary increases its strength. By removing the oc-

Fig. 10. Testing Titanium Steel by subjecting it to Alternating Vibrational Strains

Fig. 11. Machine for giving Impact Tests to Steel

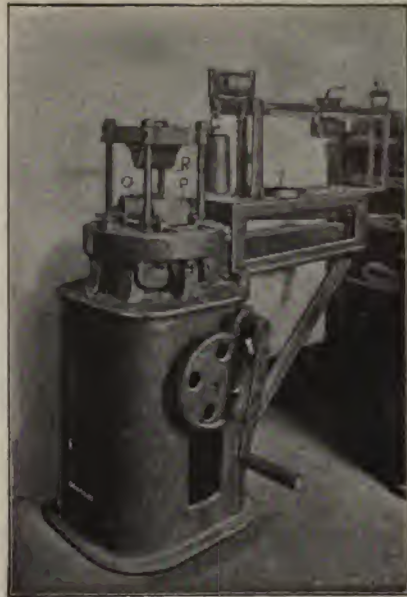

Fig. 12. Machine for Testing the Strength of Titanium-treated Cast Iron

cluded gases and other impurities it also increases the resistance of the steel to corrosion.

Alternating vibrational strains are produced in the metal by the machine shown in Fig. 10. In this the test piece is held at *I* while the part of the machine shown at *J* is rocked back and forth to alternately bend the samples ¼ inch either way from the vertical. This test has also given some very good results for titanium steel. Both

machines have a cyclometer attached to register the number of revolutions or alternations given the sample.

Impact tests of the steel are made in the machine shown in Fig. 11. In this, only the lower part of the machine could be shown, as it passes through the ceiling. The upper part is only a guide for the weight and, in this machine, extends 20 feet above the platen. The test piece is placed on platen *K*, and weight *L* is dropped on it, from a given height. When weight *L* strikes the test piece, the springs under platen *K* cause pointer *N* to register the foot-pounds of the blow, on dial *M*.

Some tests on titanium treated steel rails that were 85 pounds to the yard were conducted in a similar way. Rails were cut up into 3-foot 6-inch lengths, laid on supports three feet apart, and a weight

TABLE X. TURNING TESTS WITH TOOL STEEL

Number of Tool	Titanium Content, Per Cent	Depth of Cut in Inches	Width of Chip in Inches	Speed in Feet per Minute	Minutes Tool was Used	Condition of Tool at End
1	None	$\frac{1}{64}$	$\frac{1}{4}$	27	70.0	Blunt
2	None	$\frac{1}{64}$	$\frac{1}{4}$	27	71.5	Blunt
3	0.25	$\frac{1}{64}$	$\frac{1}{4}$	27	100.2	Blunt
4	0.35	$\frac{1}{64}$	$\frac{1}{4}$	27	117.2	Blunt
5	None	$\frac{1}{64}$	$\frac{1}{8}$	32	28.2	Blunt
6	None	$\frac{1}{64}$	$\frac{1}{8}$	32	42.8	Blunt
7	0.25	$\frac{1}{64}$	$\frac{1}{8}$	32	63.3	Blunt
8	0.35	$\frac{1}{64}$	$\frac{1}{8}$	32	76.4	Blunt
9	None	$\frac{1}{64}$	$\frac{3}{32}$	50	25.4	Blunt
10	None	$\frac{1}{64}$	$\frac{3}{32}$	50	70.6	Blunt
11	0.25	$\frac{1}{64}$	$\frac{3}{32}$	50	97.2	Blunt
12	0.35	$\frac{1}{64}$	$\frac{3}{32}$	50	133.2	Blunt

Machinery

of 2000 pounds dropped on them from a height of 17 feet. Three blows were given on the head and the deflection measured. Then the rail was turned over and the fourth and fifth blows were given on the base. Table IX gives the results of these tests.

Titanium in Tool Steels

Titanium-treated steel can be made by the crucible process and only increases the cost of the metal $2.50 per ton when one per cent of titanium is used. Some experiments and tests were conducted on titanium steels in Sheffield, England. In these steels enough titanium was used to give 0.25 per cent and 0.35 per cent of the titanium in the finished steel. An ordinary tool steel with a tensile strength of 127,000 pounds per square inch was used. Six lathe tools were made from it before the titanium was used. The metal was then treated with titanium and six more tools made. One tool with titanium and one without turned the same bar at the same time. Thus tools 1 and 3, 5 and 7, and 9 and 11 were used together and tools 2 and 4, 6 and 8, and 10 and 12 were used likewise. The tools were all given the same heat-treatment and the results that were obtained are shown in Table X.

In some experiments that were made by tool-steel makers in the Pittsburg district, it was found that if 0.50 per cent of titanium was retained in the steel, it would give cutting tools much greater durability and high-speed qualities. A special method is required, however, to retain any of the titanium in the steel, as its great affinity for oxygen and nitrogen causes it to go off into the slag. By removing the impurities, the titanium causes the metal to heat more slowly in the forge and also to retain the heat longer after it has been worked and become cold. This property of heating more slowly causes the cutting edge to last longer, as the temper is retained longer. The resistance to corrosion will also keep the tools from rusting, to a certain degree, when laid away.

As steel treated with titanium shows greater resistance to abrasive and frictional wear, it heats up more slowly from friction. Thus

TABLE XI. TESTS OF GRAY IRON CASTINGS WITH AND WITHOUT TITANIUM

Without Titanium			With 0.5 Per Cent of Titanium		
Sample	Crushing Strength in Pounds	Deflection in Inches	Sample	Crushing Strength in Pounds	Deflection in Inches
1	2,240	0.10	1	3,050	0.09
2	2,260	0.10	2	3,140	0.10
3	2,010	0.09	3	3,150	0.10
4	1,840	0.08	4	3,280	0.10
5	1,970	0.08	5	2,850	0.10
6	2,150	0.10	6	2,990	0.09
Average	2,078	0.09	Average	3,068	0.10

Machinery

whether it be the tool or the work that is treated with titanium, the machine work can be performed more quickly, as the cutting speed can be increased; whether the tools be of the carbon or high-speed kind, makes no difference about increasing the speed. One instance of the slow heating of titanium treated metal was shown in some ingot molds that did not show red in the dark when filled with molten metal; whereas ordinary ingot molds filled at the same time and standing beside them, were distinctly red hot.

Steel castings that have been treated with titanium are more blue in color, freer from blow-holes and brittleness and heat up more slowly from cutting tools than ordinary steel castings; they can thus be machined more easily and rapidly. The No. 3 Government specifications for cast steel have been difficult to meet without resorting to several heat-treatments. They call for a tensile strength of 85,000 pounds per square inch, an elastic limit of 45,000 pounds per square inch, an elongation after rupture of 12 per cent, and a contraction of 18 per cent. By the use of 8 pounds of 10 to 15 per cent ferro-titanium to a ton of metal, the difficulties have been overcome by one foundry.

In fifteen heats before the titanium was used, the average tensile strength of castings after the first annealing was 81,633 pounds per square inch, the elastic limit was 47,233 pounds per square inch, the elongation, 15.1 per cent, and the contraction, 18.9 per cent. The fifteen heats after this, that contained titanium, produced castings with an average tensile strength of 91,533 pounds per square inch, an elastic limit of 50,000 pounds per square inch, an elongation of 19.2 per cent, and a contraction of 24.3 per cent. The steel that entered into the castings was made in a Tropenas converter, and was free from blow-holes, homogeneous, and very uniform in its properties.

Very exhaustive tests have been made of the effect of titanium in cast iron and Table XI shows the comparison between gray iron as cast without titanium and with 0.5 per cent of titanium added. These tests were made in the machine shown in Fig. 12. The test bar is laid on the supports *O* and *P* while block *R* is forced down on it. The deflection and number of pounds required to break the piece are then measured. The transverse strength has been increased from 17 to 23 per cent by the use of titanium. It also increases the breaking stress, wearing qualities and hardness in the chill of cast iron; but it decreases the chilling effect.

CHAPTER VI

NATURAL ALLOY STEEL

Natural alloy steel is rapidly becoming an important material in the manufacturing field. It derives its name from the fact that the steel is manufactured from an ore in which nickel and chromium are alloyed by nature. While such ores have been known to exist for some time, it is only within the last decade that ores were discovered that had a uniform composition and existed in quantities sufficiently large to warrant their manufacture into steel.

Shortly after the Spanish-American War, such ore was discovered at Mayari and Moa in the Province of Oriente, in the eastern part of Cuba. These ores showed a remarkable uniformity of composition and covered some 25,000 acres on a plateau on the northern slope of a mountain range. In this place there is something like 1,000,000,000 tons of ore in sight, low in phosphorus and sulphur. The Pennsylvania Steel Co., Steelton, Pa., obtained the control of these ore beds and is, besides the Maryland Steel Co., Sparrows Point, Md., the only company manufacturing steel billets, blooms, bars, and miscellaneous forgings from the ore. The steel made by the Pennsylvania Steel Co. is known by the trade name "Mayari steel." Other companies purchase the billets, bars, etc., and roll and forge them into commercial shapes. The Philadelphia Steel & Forge Co., Philadelphia, Pa., is one of these firms; it has given the product the trade name "natural alloy steel," while the Carpenter Steel Co., Reading, Pa., calls it "Samson steel." Both of these latter firms make a specialty of rolling and forging shapes suitable for automobile parts, but they also manufacture the steel into bars and shapes that can be used for die-blocks, spindles, tools, and for numerous other purposes.

The various grades of steel into which this ore is manufactured contain from 1.00 to 1.50 per cent of nickel; from 0.20 to 0.70 per cent of chromium; from 0.30 to 1.50 per cent of carbon; and from 0.50 to 0.80 per cent of manganese; the silicon is kept below 0.20 per cent, and the phosphorus and sulphur below 0.04 per cent. These two latter elements, however, seldom reach 0.035 per cent, and a phosphorus content that is below 0.02 per cent is often obtained. The commercial stock is manufactured in two grades, one of which contains between 0.20 and 0.40 per cent of chromium, and the other between 0.40 and 0.70 per cent. Both of these can be obtained in any of the following carbon percentages: 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45 and 0.50 per cent. Another brand that is used to a large extent for leaf springs, and also for other purposes, contains from 0.90 to 1.50 per cent of carbon and between 0.20 and 0.40 per cent of manganese, which is in accordance with the spring steel specifications of the Pennsylvania

Railroad Co. Titanium, vanadium and other purifying materials can be added to the steel if it is so desired, and thus further enhance the physical properties.

These natural alloy steels are carefully made by the open-hearth process and are, in the heat-treated condition, in every way the equal to 3½ per cent nickel steel. In some ways they are superior to this steel and especially is this true of the grade that contains the higher percentages of chromium, or when they are manufactured into parts that have a comparatively large sectional area. They are also cheaper

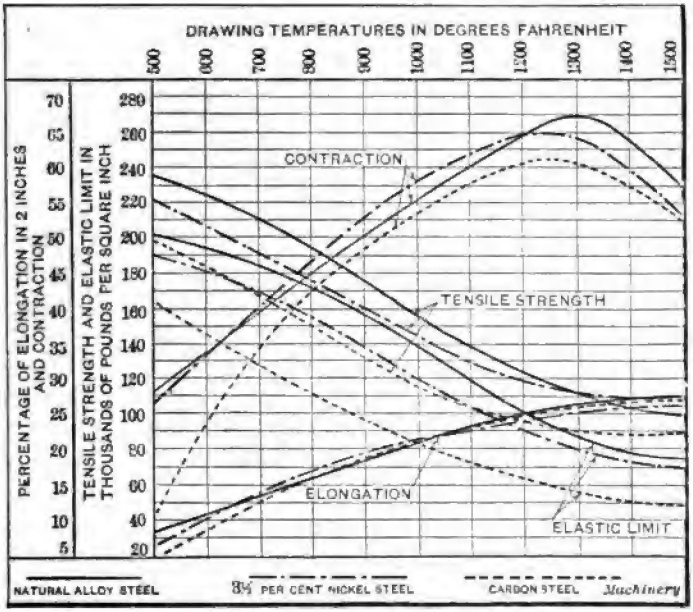

Fig. 13. Comparison of Characteristics of Natural Alloy, Nickel and Carbon Steels

than the nickel steels made by the same process, and in the billet form they are but little higher in price than the ordinary carbon steels. The high-grade and high-priced nickel-chromium steels are the only ones that are superior to the natural alloy steels in static strength, and this is largely due to the fact that they are usually made by the crucible process and contain a higher percentage of chromium, this being approximately 1.00 and 1.50 per cent in the two best brands.

Properties of Natural Alloy Steels

For comparing the static strength, a large number of tests were made with natural alloy, nickel and carbon steels that contained 0.40 per cent of carbon and were hardened at the critical point and then drawn at various temperatures between 500 and 1500 degrees F. The average results obtained from these three kinds of steels are shown

in Fig. 13. The steels compared all contained 0.40 per cent carbon. The natural alloy steel was quenched at 1520 degrees F.; the 3½ per cent nickel steel at 1500 degrees F.; and the carbon steel at 1530 degrees F. The average strength of each steel at a given drawing temperature can be obtained by following downward the line indicating the desired number of degrees, until it meets the curve of the tensile strength, elastic limit, elongation or contraction, according to which is to be found, and from this point following the horizontal line to the left, where the number of pounds per square inch, or the percentage, is recorded. In Table XII are shown the average elastic limit and ultimate strength as ascertained in some torsional tests made at the Pennsylvania State College. All heat-treated specimens were hardened and drawn to develop the best properties for driving shafts, axles, etc.

TABLE XII. AVERAGE FIBER STRESS IN POUNDS PER SQUARE INCH
TORSIONAL TESTS MADE AT PENNSYLVANIA STATE COLLEGE

Kind of Steel		Natural Alloy Steel	3½ Per Cent Nickel Steel	Carbon Steel
Annealed	Elastic limit	41,500	40,800	32,500
	Ultimate strength	93,400	78,200	75,100
Heat-treated	Elastic limit	93,600	76,400	60,500
	Ultimate strength	130,200	108,000	102,400

Machinery

Much care has to be taken in manufacturing the ordinary nickel or nickel-chromium steels to prevent either of these elements from segregating in the bath or when teeming it into ingots. This is largely due to the fact that the nickel and chromium are additions and the bath must be heated to a comparatively high temperature just before teeming. In the natural alloy steel, however, the nickel and chromium are alloyed in the ore and are present in the bath from the time the melting operation starts until the finished steel is poured into ingots. Hence the bath does not have to be heated to any higher temperature at the time of tapping than do ordinary steels, and any tendency towards segregation is largely overcome. Thus, the elements are more uniformly distributed throughout the mass, and a homogeneous metal is obtained. When such elements segregate and the steel is rolled, they produce laminations in the metal which have a very injurious effect upon its strength, especially at right angles to the direction in which they are rolled.

Influence of Chromium

The extreme hardness produced by chromium makes it necessary to use comparatively small percentages in steels that are to be machined. When the chromium content reaches 2.00 per cent, the steel is very difficult to cut when cold, and when higher percentages are used, the

steel cannot be cut with any kind of cutting tools and must be ground to shape, this latter being an expensive method to pursue. Thus, in the high-grade nickel-chromium steels that are to be manufactured into parts of machines or instruments, the chromium content is usually about or below 1.50 per cent. Owing to the difficulty of working even this steel, however, many grades of steel have been made with a chromium content of 0.25, 0.50 and 0.75 per cent, and it is as a substitute for these grades that natural alloy steel can be used.

In steel, chromium gives the metal a hardness similar to that given by carbon, but to a lesser degree for the same percentage. It is a hardness, however, that makes the cohesion of the molecules much greater and thus greatly increases the static and dynamic properties. Chromium also greatly retards the formation of any grain or fiber, and thus makes the steel practically grainless. All of these effects of chromium upon steel cause it to increase its tensile strength, elastic limit, hardness, resistance to torsion, shocks, vibrations, or other stresses, and also increase its wearing qualitities and prolong its life.

Influence of Nickel

Nickel increases the ductility, toughness and resiliency of steel, and also increases its susceptibility to heat-treatment. It reduces the size of the crystalline structure and tends to prevent microscopic cracks that are liable to develop into larger cracks and produce ruptures. It was first added to steel to overcome the property of "sudden rupture" which is inherent in all carbon steels. It reduces the tendency of steels to become damaged by overheating in hardening, and shows its effect in the hardening operations by making the tensile strength and elastic limit two and three times that of the untreated, or annealed steel. Nickel raises the elastic ratio in steels, *i. e.*, the elastic limit is raised to a higher percentage of the tensile strength. This condition is always sought for in the better grades of steel.

The two elements mentioned, therefore, greatly enhance the value of natural alloy steel for the various parts of machinery that are subjected to severe stresses. This steel also resists corrosion much better than other steels, the sulphuric acid test showing that it corrodes from 10 to 20 per cent less than the low carbon and manganese, basic and open-hearth metals with nearly all of the impurities removed, which have been given such names as "pure ingot iron," "old-fashioned iron," "toncan metal," etc. While there are some that doubt whether this test agrees with the results obtained from exposure to actual weather conditions, it is generally conceded that steels containing nickel corrode less rapidly than carbon steels and wrought iron.

Working Alloy Steels

Natural alloy steel can be hammered, rolled, drop-forged, pressed, stamped, or machined with the same ease and at the same temperatures as carbon steel; no special precautions are necessary. The high-grade nickel-chromium steel (on the other hand, must be heated to

a white heat before being hammered, rolled, or drop-forged. The high temperature must also be maintained during the mechanical working, and if it falls very much, the steel must be reheated. Nickel steels must also be carefully handled when thus working them, and hence it will be seen that natural alloy steel is more cheaply worked into shape than other alloy steels. Natural alloy steel is similar to

TABLE XIII. EFFECT OF HEAT-TREATMENT ON FORGINGS OF NATURAL ALLOY STEELS

Per Cent of Carbon	Annealed				Heated to 1550° F. and Quenched in Water — Tempered at 1050° F.			
	Pounds per Sq. Inch		Per Cent		Pounds per Sq. Inch		Per Cent	
	Tensile Strength	Elastic Limit	Elongation	Contraction	Tensile Strength	Elastic Limit	Elongation	Contraction
0.30	89,500	57,500	28.0	51.9	106,500	76,000	21.0	51.9
0.40	88,500	56,000	29.0	51.9	112,500	88,000	23.0	59.8
0.50	119,500	68,000	18.0	87.1	185,000	107,000	16.5	46.2

Per Cent of Carbon	Heated to 1550° F. and Quenched in Water — Tempered at 1000° F.				Heated to 1550° F. and Quenched in Water — Tempered at 600° F.			
	Pounds per Sq. Inch		Per Cent		Pounds per Sq. Inch		Per Cent	
	Tensile Strength	Elastic Limit	Elongation	Contraction	Tensile Strength	Elastic Limit	Elongation	Contraction
0.30	131,000	114,000	17.5	51.9	193,000	177,000	8.5	30.7
0.40	130,500	118.500	18.5	51.9	209,000	188,000	10.5	37.1
0.50	155,000	138,500	14.0	43.0	252,000	232,000	7.0	24.0

other alloy steels, however, in that it is very difficult to weld by ordinary methods; parts that are to be submitted to great strains should not be welded together. Like other alloy steels it can be welded with more or less success by the various electric welding processes and machines that are on the market. The electric machines that squeeze the parts together are preferable, as these prevent the grain from becoming coarse, as it does when other methods are used. If the steel is hammered after welding, this will aid in refining the grain that has become coarse at the weld. By careful workmanship with the

electric process it is often possible to obtain from 70 to 80 per cent efficiency at the weld, whereas an efficiency of between 30 and 40 per cent is all that can be obtained by ordinary welding methods.

Natural alloy steels, like all other steels, will attain the highest strength only when properly heat-treated. In the untreated or annealed state, they show a tensile strength and elastic limit that is from 8000 to 10,000 pounds per square inch higher than carbon steels of the same carbon content, but when properly heat-treated they compare favorably with other alloy steels. Some figures that were obtained from annealed and heat-treated forgings are given in Table XIII.

Heat Treatment

The heat-treatment is practically the same as that given other steels. The hardening temperature may vary somewhat, but not to any great extent. The brands containing from 0.15 to 0.20 per cent carbon should be heated to 1500 degrees F. and quenched in brine to obtain the best results. Those with a carbon content between 0.30 and 0.50 per cent should be heated to 1550 degrees F. They can then be quenched in water as readily as carbon steels, although oil and special liquid compositions can be used for the quenching bath with equally good results. The temperature at which they are afterwards drawn, of course, varies with the kind of work that the finished piece would be called upon to perform.

When hardening steel, a cold piece should never be put in a highly heated furnace, as it is liable to crack. It should either be preheated to above 600 degrees F., or it should be put in a cold furnace and heated up slowly. It should soak in the heat at the hardening temperature long enough for the piece to heat clear to its center. The work should never lie directly on the hearth of the furnace, but should be raised sufficiently to allow the heat to attack it from all sides, and it should be supported in a way that will not allow it to sag, as hot steel is soft and pliable and likely to bend. The axis of the piece should be vertical when plunging it into the quenching bath to prevent unequal contraction in cooling. The work should never have sharp grooves, corners, or other features, that easily develop cracks when the steel is heated and quenched.

In drawing steel, a furnace should never be used that is hotter than the drawing temperature. It is difficult to judge the temperature that the work has attained in such a furnace and get within 50 degrees of the desired results. If the piece attains too high a temperature, it will be softer than that required, and if the drawing is too low, it will not be soft enough. With a tempering furnace held at the correct temperature, the work can be allowed to remain in it until it has absorbed the heat of the furnace and then accurate results can be obtained. A difference of 50 degrees in the drawing temperature is of much more importance than 50 degrees in the hardening temperature, and is more difficult to estimate.

Casehardening

Carbonizing or casehardening can be performed in any of the various ways that are now used for other steels. Pieces can be heated to a red heat and quenched in cyanide to give them a depth of casehardened surface of a few hundredths of an inch; or they can be packed in iron boxes with bone and charcoal, or other carbonizing materials, and then heated in furnaces for a time that is sufficient to give them a greater depth of penetration. Where the output would warrant it, however, the special furnaces that have been designed for carbonizing with gas would probably give the most uniform results, if the

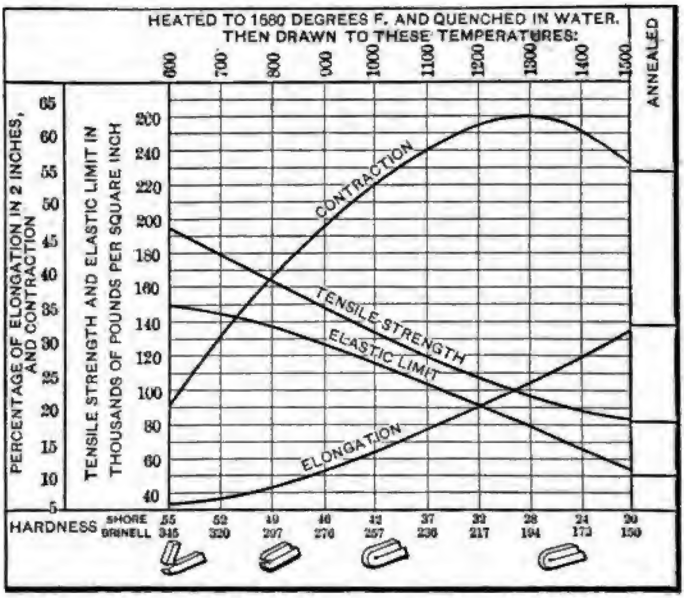

Fig. 14. Physical Properties of 0.20 Per Cent Carbon Natural Alloy Steel

work is properly done. This is also the cheaper method when large quantities are worked or handled.

In any case, however, the carbonizing mixtures should not contain over 15 per cent of moisture or 0.50 per cent sulphur. Moisture might cause a pitting of the steel which is liable to cause it to chip on the surface, while the sulphur soaks into the casehardened shell to a considerable extent. A carbonizing temperature of from 1750 to 1800 degrees F. can be used, and this will probably give the most rapid absorption and most uniform composition of the case. The time the steel is submitted to this temperature depends upon the depth of carbonized case desired.

After carbonizing, the work should be allowed to cool slowly until it becomes black in daylight. It should then be reheated to 1500 degrees *F. and quenched* in either oil or water. After this it should again be

reheated to 1350 degrees F. and again quenched in either oil or water. This double quenching gives much better results on all steels than does the ordinary practice of quenching directly from the carbonizing furnace and reheating but once to about 1375 degrees F. and quenching in oil.

In casehardened work, the core of the piece has a carbon content of about 0.20 per cent while the carbonized shell contains about 1.00 per cent. Thus, there are two steels of a different nature and these should be given different heat-treatments. In the double quenching,

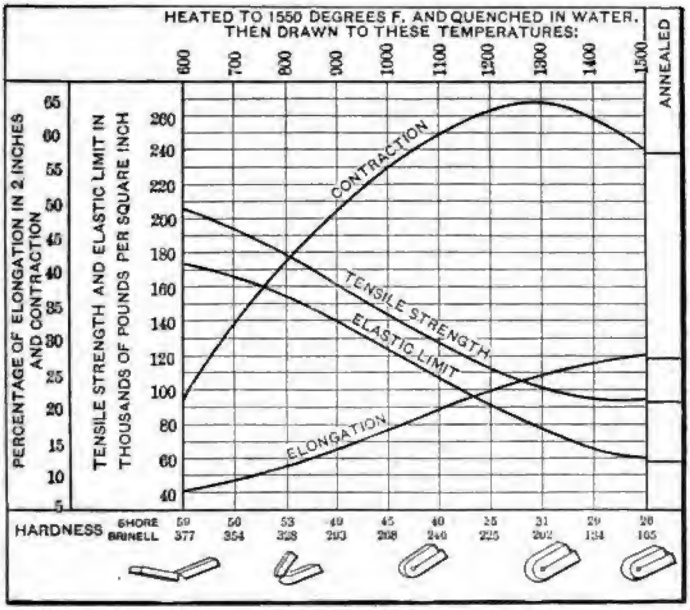

Fig. 15. Physical Properties of 0.30 Per Cent Carbon Natural Alloy Steel

the first heating and quenching hardens the core but overheats the case and makes it brittle. The second reheating restores the case to its fine-grain structure and also toughens the core, and the final quenching hardens the case.

Uses of Natural Alloy Steels

Natural alloy steels are largely used in the manufacture of automobile parts. A grade containing 0.15 per cent of carbon is often used for carbonized parts where the toughness of the core is of more importance than the strength of the steel or its ability to resist shocks. When parts are required to withstand severe shocks or strains and have a good wearing surface, steel containing 0.20 per cent of carbon is used. This grade responds more readily to heat-treatment. Thus speed-change gears, differential gears, drive gears, etc., are made from this steel. It is used without carbonizing where consider-

able toughness is required rather than strength, as in various structural parts. It is also used for cold rolling or cold pressing, and for such work as seamless tubes, small drop forgings, etc.

Tensile Strength, Elastic Limit, etc.

The tensile strength, elastic limit, elongation and contraction of this steel, as affected by various heat-treatment temperatures, are shown in Fig. 14. The vertical lines show the drawing temperatures which are marked in degrees at the top, while the horizontal lines represent the tensile strength and elastic limit and the percentage of elongation and contraction. Below the chart are given the hardness scales of the

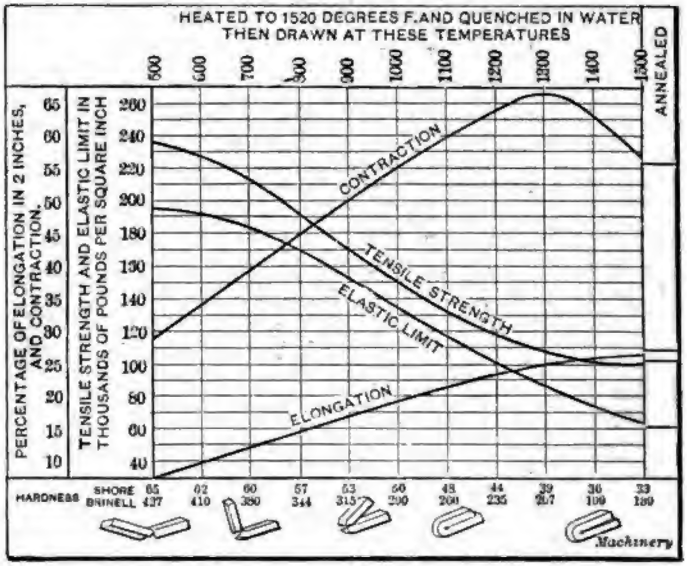

Fig. 16. Physical Properties of 0.40 Per Cent Carbon Natural Alloy Steel

steels, at these temperatures, taken from both the Shore and Brinell instruments. The cold-bend testing properties at the various temperatures are illustrated by the sketches below the chart.

From this diagram the heat-treatment that should be given this steel to obtain any of the properties that are within its range, can readily be ascertained. Thus if an elastic limit of 144,000 pounds per square inch, with a contraction of 31 per cent, is desired, the vertical line will show that the drawing temperature should be 700 degrees F. This would also give a tensile strength of about 177,000 pounds per square inch, and an elongation of about 6.5 per cent. The diagrams are based on 7/8-inch round stock; if larger pieces are used, the drawing temperature should be lowered.

The grade of steel containing 0.25 per cent carbon is usually employed for such parts as can be cold pressed, for instance, brake drums.

frame members, axle housings, etc. These parts require all the strength that can be obtained in combination with enough toughness to withstand the operation of bending into shape without developing cracks or checks. Steel 1¼ inch round, of this grade, when made into bolts, has a tensile strength of 106,000 pounds per square inch, an elastic limit of 87,500 pounds, an elongation of 26 per cent, and a contraction of 69.5 per cent.

The grade containing 0.30 per cent carbon is still harder and more applicable to heat-treated parts. Hence it is made into axles, connecting-rods, jack-shafts, drive shafts, and other parts that require considerable strength and at the same time a high degree of toughness. It is also used for drop-forgings, heavy forgings and numerous other things. The strength, hardness and cold bending properties of the 0.30 per cent natural alloy steels are shown in Fig. 15. That still greater strength can be obtained than shown in this chart was proved by a test made by one of the automobile manufacturers. The test bar was properly hardened and drawn at 600 degrees F.; the tensile strength was found to be 236,000 pounds per square inch, the elastic limit, 215,000 pounds, the elongation in two inches, 10.8 per cent, and the contraction, 36 per cent.

The grades containing 0.35 and 0.40 per cent carbon are used for spindles, rear axles, crankshafts, etc. From the 0.40 per cent grade are also made locomotive driving axles and heavy automobile truck axles, connecting-rods, piston-rods, steering knuckles, etc. The properties of the 0.40 per cent carbon grades are shown in Fig. 16. Some finished crankshafts, 2½ inches in diameter of the 0.35 per cent grade, had a tensile strength of 148,400 pounds per square inch, an elastic limit of 127,300 pounds, an elongation in two inches of 15.3 per cent, and a contraction of 53.8 per cent.

The 0.45 and 0.50 per cent carbon grades are used where extreme strength is needed in combination with considerable ductility. Thus, transmission gears that are to be heat-treated without carbonizing are usually made from this brand. The strength when heat-treated will, of course, be greater than shown in Fig. 16, but the ductility will be reduced.

At the present time there seems to be a tendency to "load" steels with alloying materials, and thus make them difficult to forge, weld, machine, or heat-treat; the results obtained do not always warrant the high prices of the finished parts. This natural alloy steel, however, is not overloaded with such alloying materials, but at the same time has properties that are well within the specifications for which many manufacturers are using much more expensive steels.

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